

THERMAL MANAGEMENT DEVICE FOR AN INTEGRATED CIRCUIT

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Field of the Invention

[0001] Disclosed embodiments of the present invention relate to the field of integrated circuits, and more particularly to an electronic assembly with a thermal management device including a porous medium.

Brief Description of the Drawings

[0002] Embodiments of the invention are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings, in which the like references indicate similar elements and in which:

[0003] **Fig. 1** is a cross-sectional view of an electronic assembly including a thermal management device with a porous medium, in accordance with an embodiment of the present invention;

[0004] **Figs. 2 (a)** and **2 (b)** are cross-sectional views of an electronic assembly including a thermal management device with a porous medium coupled to a heat source, in accordance with an embodiment of the present invention;

[0005] **Fig. 3 (a)** is a cross-sectional view of an electronic assembly including a thermal management device with a porous medium with an accompanying illustration of an evaporation/condensation cycle, in accordance with an embodiment of the present invention;

[0006] **Fig. 3 (b)** is a heat graph corresponding to the temperature across the surface of the heat source of **Fig. 3 (a)**, in accordance with an embodiment of the present invention; and

[0007] **Fig. 4** depicts a system including an electronic assembly in accordance with an embodiment of the present invention.

Detailed Description of Embodiments of the Invention

[0008] In the following detailed description, reference is made to the accompanying drawings which form a part hereof wherein like numerals designate like parts throughout, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the embodiments of the present invention. It should also be noted that directions such as up, down, back, and front may be used in the discussion of the drawings. These directions are used to facilitate the discussion of the drawings and are not intended to restrict the application of the embodiments of this invention. Therefore, the following detailed description is not to be taken in a limiting sense and the scope of the embodiments of the present invention are defined by the appended claims and their equivalents.

[0009] **Fig. 1** illustrates a cross-sectional view of an electronic assembly **20** including a thermal management device **38** in accordance with an embodiment of this invention. In this embodiment the thermal management device **38**, including a porous medium **56**, may be coupled to a heat source **24** to at least facilitate management of heat generated by the heat source **24**. This facilitation of heat management of this embodiment may include thermally coupling the heat source **24** to a remote heat exchanger.

[0010] The heat source **24** could include an integrated circuit, which may be formed in a rectangular piece of semiconductor material called a chip or a die.

Examples of the semiconductor material include, but are not limited to silicon, silicon on sapphire, or gallium arsenide. The heat source **24** could contain one or more die attached to a substrate **28** for support, to interconnect multiple components, and/or to facilitate electrical connections with other components. The heat source **24** may be attached to the substrate **28** by solder ball connections known as controlled collapse chip connectors (C4), or by some other means. The heat source **24** combined with the substrate **28** may be referred to as a first-level package.

[0011] The first-level package may be connected to a board **34** in order to interconnect multiple components such as other die, high-power resistors, mechanical switches, capacitors, etc., which may not be readily placed onto the substrate **28**.

Examples of the board **34** could include, but are not limited to a carrier, a printed circuit board (PCB), a printed circuit card (PCC), and a motherboard. Board materials could include, but are not limited to ceramic (thick-filmed, cofired, or thin-filmed), plastic, and glass. The first-level packages can be mounted directly onto the board **34** by solder balls, by a pin/socket connection, or by some other means.

[0012] In one embodiment, the porous medium **56** may be substantially disposed within a case **48**. The case **48** may have an inlet **40** and an outlet **44**. In one embodiment the inlet **40** may be coupled to a pump and the outlet **44** coupled to a heat exchanger by pipes that are adapted to transport cooling fluids between the components. The pump, which may include an external motor and a pumping mechanism internal to the pipe, may create a pressure change to at least assist the flow

of the cooling fluid from the inlet **40** to the outlet **44** through the porous medium **56**.

This may result in interstitial movement of the cooling fluid over an extended surface area. The extended surface area may result in more contact, and therefore potentially more convection heat transfer between the porous medium **56** and the cooling fluid.

The total contact surface area may be related to the porosity of the porous medium. In one embodiment of the present invention the porosity of the porous medium may be between 80%-95% by volume fraction of air.

[0013] The porous medium **56** may also serve to enhance the heat transfer coefficient due to local thermal dispersion caused by recirculating eddies that are shed in the wake of fluid flow past fibers of the porous medium **56**. This, in turn may help to reduce the thermal resistance from the heat source **24** to the heat exchanger, which could increase the total amount of heat transferred per volume of cooling fluid passed through the porous medium **56**. The cooling fluid may exit the case **48** through the outlet **44** and transfer a portion of the thermal energy from the heat source **24** to the remote heat exchanger. The heat exchanger may be any known or to be designed heat dissipation mechanism. In one embodiment the heat exchanger may dissipate excess thermal energy from the cooling fluid and present the fluid to the pump so that it may be reintroduced to the thermal management device **38**. Examples of the cooling fluid may include, but are not limited to a gas (e.g., air) and a liquid (e.g., water, alcohol, perfluorinated liquids, etc.).

[0014] In one embodiment, the porous medium **56** may be a microporous metal foam that includes numerous interlaced and seemingly randomly placed pore channels. In one embodiment the pore diameters of the microporous foam may be between 50 μm

– 1 mm. The heat transfer, or the amount of thermal energy that can be removed from the heat source **24** per volume of cooling fluid, may be roughly inversely proportional to the pore diameter of the porous medium **56**. Additionally, the pressure drop of the cooling liquid may be roughly inversely proportional to the pore diameter. Therefore, it follows that a high heat transfer may require small pore sizes, which in turn may result in large pressure drops. Pressure drops of these magnitudes may be handled by any suitably efficient pumps that are known or to be designed. The microporous metal foam may include, for example, aluminum, carbon, or nickel.

[0015] The parameters of the porous medium **56** may be customized for application in a particular embodiment. For example, in one embodiment, the pore size may be adjusted in portions of the porous medium **56** to increase fluid flow through those areas. Additional embodiments may include the porous medium **56** being compressed in a particular direction to give elongated pores that have the potential of lowering the pressure drop for a given area, possibly without an appreciable increase in thermal resistance.

[0016] In one embodiment the porous medium **56** may be disposed within, and substantially filling the case **48**. The porous medium **56** may be coupled to the internal portion of the case by a thermal interface material **58** to at least facilitate the heat transfer of the thermal management device **38** by providing a thermally conductive path between the case **48** and the porous medium **56**.

[0017] A wide variety of suitable thermal interface materials may be used in various embodiments in accordance with this invention. Some attributes that may be considered with respect to a particular embodiment may be a low thermal resistance,

secure mechanical adhesion, and ease of application. Additionally, particular design considerations of a given embodiment could be factored in to decide what type of thermal interface material to use. For example, in one embodiment a thermal interface material with a low thermal resistance but poor mechanical adhesion could be supplemented by providing for additional mechanical connectors such as screws, clips, or spring-loaded pins. Examples of types of thermal interface materials include, but are not limited to, a thin layer of solder paste, phase-change materials, thermal adhesives (e.g., a highly filled epoxy or acrylic), double-sided thermal tape, and thermal interface pads.

[0018] The process for attaching the porous medium **56** and the case **48** may vary depending on the type of materials involved in a particular embodiment. In an embodiment that uses a solder paste as the thermal interface material **58**, the thermal management device **38** may be placed in a reflow oven in order to reflow the solder.

[0019] In another embodiment, it may be possible to “grow” the porous medium **56** directly on the case **48**. In this embodiment a granular structuring layer (e.g., salt) may be placed in the area where the porous medium is desired. The grain size of the structuring layer may be roughly the desired pore size of the porous medium **56**. The salt used in this example may have a diameter of approximately 0.5 mm. A fine metal powder, e.g., aluminum, may be added over the salt. Because of the relative size difference, the powder may fill in the gaps between the salt grains. The mixture could then be heated to the melting temperature of the powder (which may be less than structuring layer). Once the metal flows and the mixture cools, the salt may be removed

by running water which may leave an aluminum metal foam with a pore size of approximately 0.5 mm attached directly to the case **48**.

[0020] The case **48** may be made of a conductive material to reduce the thermal resistance in the path between the heat source **24** and the porous medium **56**. In one embodiment, only the bottom portion of the case **48**, that is the side that is in closest relation to the heat source, may be made of a conductive material. The case **48** may be constructed of several pieces with the final assembly occurring after the porous medium **56** is positioned on the inside. In one embodiment, the case includes at least a top and bottom copper plate which corresponds roughly to the size of the heat source **24**. The case **48** could be made of any type of conductive material including, but not limited to, copper (Cu), aluminum (Al), and aluminum silicon carbide (AlSiC). Design considerations for choosing the case material for a given embodiment may include conductivity, cost, manufacturability, coefficient of thermal expansion, etc.

[0021] In one embodiment, the case **48** may be attached to the heat source **24** with a thermal interface material similar to the one used to attach the porous medium to the interior portion of the case **48**. In an embodiment using a solder paste as a thermal interface material, the solder may have a lower reflow temperature than that of the C4 connections that attach the heat source **24** to the substrate **28** to prevent any unintentional reflowing.

[0022] In one embodiment a heat spreader (not shown) may be placed over the heat source **24** and attached to the substrate **28**. The heat spreader may be used as an intermediary step to disperse at least a portion of the heat generated by the heat source **24** over its surface area. The heat spreader may be attached to the substrate **28** by a

sealant material and thermally coupled to the heat source **24** with a thermal interface material. In this embodiment, the thermal management device may be placed on the heat spreader with a thermal interface material, similar to above embodiment.

[0023] In one embodiment the thermal management device **38** may use two-phase cooling. Two-phase cooling may occur when heat from the heat source **24** transforms a cooling liquid into a vapor. As the vapor flows away from the heat source **24** towards the heat exchanger it may cool and condense back into liquid, which may result in a release of its latent heat of vaporization. The fibers and overall density of the porous medium **56** may prevent the formation of large air bubbles that may inhibit heat transfer and restrict the quality of the vapor-fluid mixture at the outlet of the thermal management device **38**. Additionally, the fibers on the porous medium **56** near the heat source **24** may assist the onset of boiling by acting as nucleation sites. Whether or not the cooling fluid will evaporate and lead to two-phase cooling may depend on the amount of heat generated by the heat source **24**, as well as the flow rate of the cooling fluid. For example, in one embodiment high heat production and low flow rates may be more likely to result in two-phase flows.

[0024] As the cooling liquid vaporizes over the hot spots of the heat source there may be a corresponding increase in the pressure drop in the area. With the interconnected nature of the pore channels of embodiments of this invention there may be an equilibration of pressure from high to low pressure areas. This could result in cooling liquid flowing to the areas associated with concentrated thermal energy, thereby potentially increasing the overall heat transfer of the system.

[0025] **Fig. 2** depicts an exploded **(a)** and combined **(b)** cross-sectional view of an electronic assembly **60** with a thermal management device **64** in accordance with one embodiment of the present invention. In this embodiment the porous medium **56** may be coupled to the heat source **24**. The porous medium **56** may be coupled to the heat source **24** by a similar process as it was attached to the case **48** discussed with reference to the embodiment depicted in **Fig. 1**. In the present embodiment, the case **70** may be adapted to fit over the porous medium **56** by having a cavity **72**. The porous medium **56** may be attached to the interior portion of the cavity **72** by a thermal interface material, or by some other means.

[0026] In one embodiment the cavity **72** may be the same size or even slightly smaller than the porous medium **56** and the case **70** may be heated such that the cavity **72** expands large enough to be positioned over the porous medium **56**. As the case **70** cools down it may shrink to form a tight fit. The case **70** may have an inlet **71** and outlet **73** for the cooling fluid flow. The inlet **71** and outlet **73** may be attached to a pump and heat exchanger, respectively, similar to the embodiment described in **Fig. 1**. In one embodiment a watertight seal may be formed between the heat source **24** and the case **70**, which may prevent cooling fluid from leaking from the thermal management device **64**. In an embodiment an epoxy sealant **76** may be used to seal any gap between the case **70** and the die. As shown in the illustrated embodiment, the epoxy sealant **76** may also serve to provide a seal between the case **70** and the substrate **28**, which may reinforce the watertight seal. The epoxy sealant **76** may also at least facilitate the support of the thermal management device **64**, which could reduce the amount of

torsion transferred to the connections between the porous medium **56**, the heat source **24** and the substrate **28**.

[0027] **Fig. 3 (a)** shows a cross-sectional view of an electronic assembly including a thermal management device with a porous medium **56** illustrating an evaporation/condensation cycle, in accordance with an embodiment of the present invention. In this embodiment, there may be a relative hot spot located near the middle of the heat source **24**, as shown by the corresponding temperature graph in **Fig. 3 (b)**. Die containing integrated circuits may display these non-uniform heat intensity distributions due to concentrated current flow for one reason or another. In one embodiment it may be possible to customize the case **80** and porous medium **56** to account for these concentrated heat distributions and thereby at least facilitate the thermal exchange between the heat source **24** and the heat exchanger.

[0028] The embodiment depicted by **Fig. 3 (a)**, unlike the embodiments depicted by **Fig. 1** and **Fig. 2**, may have a closed case that does not use an inlet and an outlet. In this embodiment the cooling fluid may evaporate over the hot spot of the heat source **24** and the fluid buoyancy of the vapor may create an upward fluid motion towards the top of the case **80**, which may be considered the heat exchanger of this embodiment. In this embodiment the latent heat of vaporization may be transferred to the top of the case **80** where it may be dissipated to the ambient through natural convection, or by some other means. Various embodiments may employ different types of cold plates or heat sinks attached to the top of the case **80** to assist this convection. In this embodiment as the vapor condenses back to a liquid, it may be forced to the sides of the porous medium **56**. The heavier condensed fluid may trickle down the sides of the

porous medium and collect back over the hot spot of the heat source **24**. In an alternative embodiment, the fluid may not go through a phase change, as sufficient buoyancy induced flow may result from heated fluid without the phase change. The interior of the case **80** may be designed to facilitate these cyclical two-phase flows. In one embodiment the flow paths of the vapor and condensed liquid may travel through areas of variable pore size depending on the desired fluid dynamics of the particular embodiment.

[0029] Referring to **Fig. 4**, there is illustrated one of many possible systems in which embodiments of the present invention may be used. The electronic assembly **100** may be similar to the electronic assemblies depicted in above **Figs. 1, 2, and 3**. In one embodiment, the electronic assembly **100** may include a microprocessor. In an alternate embodiment, the electronic assembly **100** may include an application specific IC (ASIC). Integrated circuits found in chipsets (e.g., graphics, sound, and control chipsets) may also be packaged in accordance with embodiments of this invention.

[0030] For the embodiment depicted by **Fig. 4**, the system **90** may also include a main memory **102**, a graphics processor **104**, a mass storage device **106**, and an input/output module **108** coupled to each other by way of a bus **110**, as shown. Examples of the memory **102** include but are not limited to static random access memory (SRAM) and dynamic random access memory (DRAM). Examples of the mass storage device **106** include but are not limited to a hard disk drive, a compact disk drive (CD), a digital versatile disk drive (DVD), and so forth. Examples of the input/output modules **108** include but are not limited to a keyboard, cursor control devices, a display, a network interface, and so forth. Examples of the bus **110** include but are not limited to

a peripheral control interface (PCI) bus, and Industry Standard Architecture (ISA) bus, and so forth. In various embodiments, the system 90 may be a wireless mobile phone, a personal digital assistant, a pocket PC, a tablet PC, a notebook PC, a desktop computer, a set-top box, an entertainment unit, a DVD player, and a server.

[0031] Although specific embodiments have been illustrated and described herein for purposes of description of the preferred embodiment, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent implementations calculated to achieve the same purposes may be substituted for the specific embodiment shown and described without departing from the scope of the present invention. Those with skill in the art will readily appreciate that the present invention may be implemented in a very wide variety of embodiments. This application is intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.